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Manian et al.

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(54) **OPTICAL AUTOFOCUS FOR USE WITH MICROTITER PLATES**

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(22) Filed: **Oct. 29, 1999**

Related U.S. Application Data

(60) Division of application No. 09/245,782, filed on Feb. 5, 1999, now Pat. No. 6,130,745, which is a continuation-in-part of application No. 09/226,842, filed on Jan. 7, 1999, now abandoned.

(51) **Int. Cl.**[7] **G01J 1/00**
(52) **U.S. Cl.** **356/123**; 356/244
(58) **Field of Search** 356/445–448, 356/244, 246, 73, 318, 417, 344, 436, 123, 124–133, 614–622; 250/458.1; 435/29; 422/63, 55–67; 369/44.13, 112

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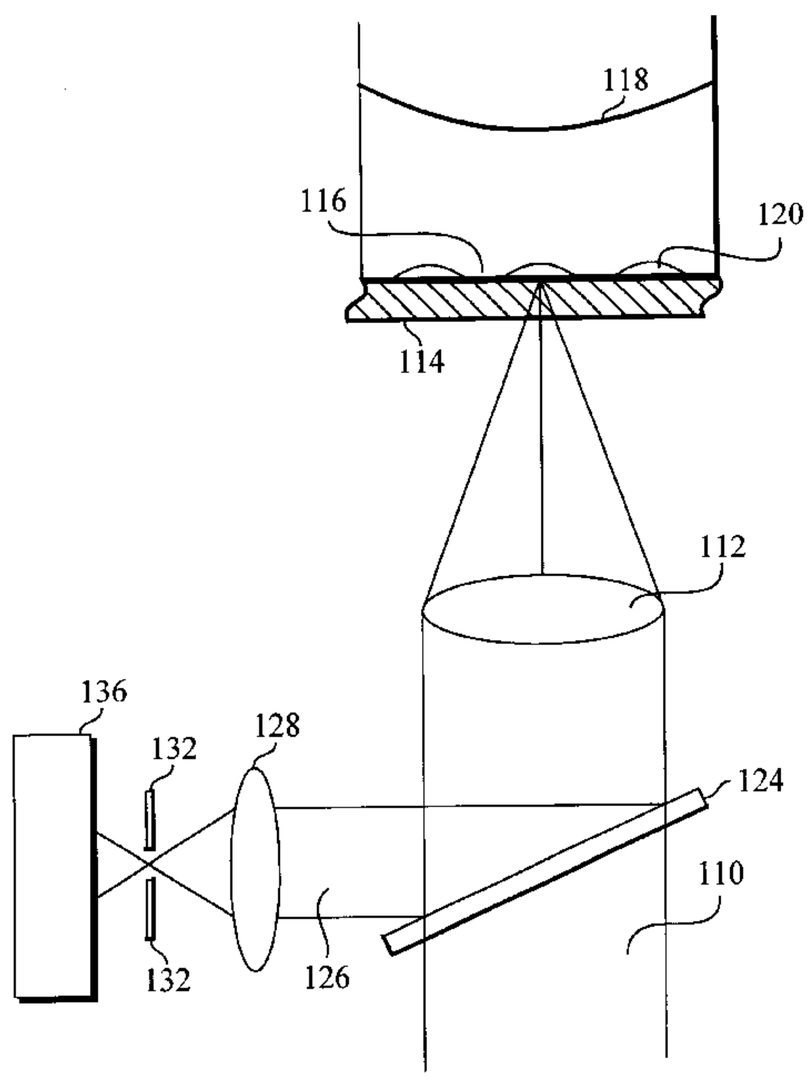
(57) **ABSTRACT**

A method and apparatus for autofocus on a target layer contained within a microplate well is provided. The instrument is capable of optically sensing a reference point on the underside of a microplate. This reference point is then used to focus light onto a target layer within the microplate well, the target layer having a location that is in defined relation to the reference point. The reference point is either a surface of the bottom of the microplate well or is an optically detectable mark on the underside of the microplate. In an alternate embodiment, a light position sensitive detector is used to enable deterministic autofocus for a plurality of wells on a microplate.

13 Claims, 10 Drawing Sheets



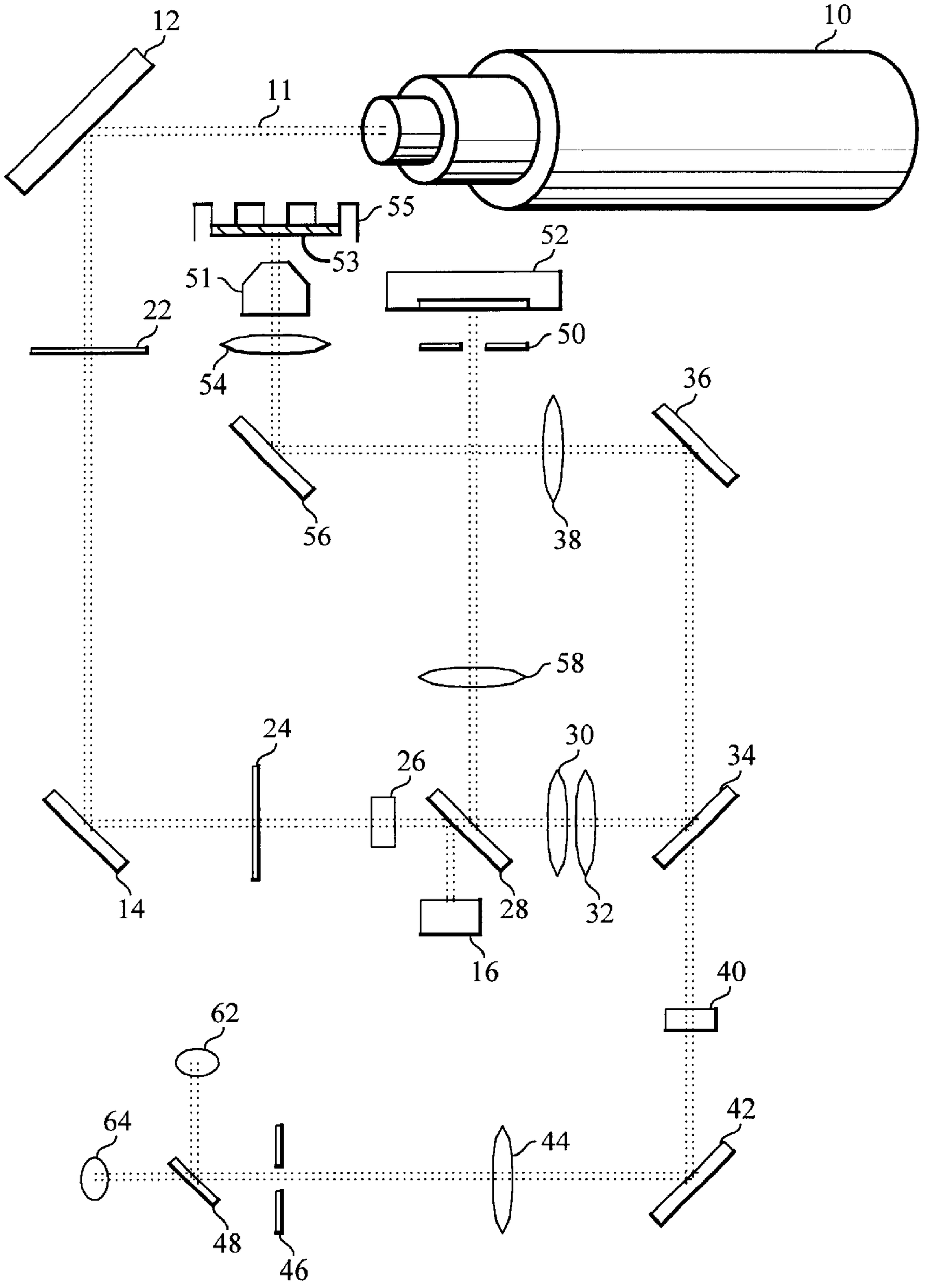

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Fig. 1

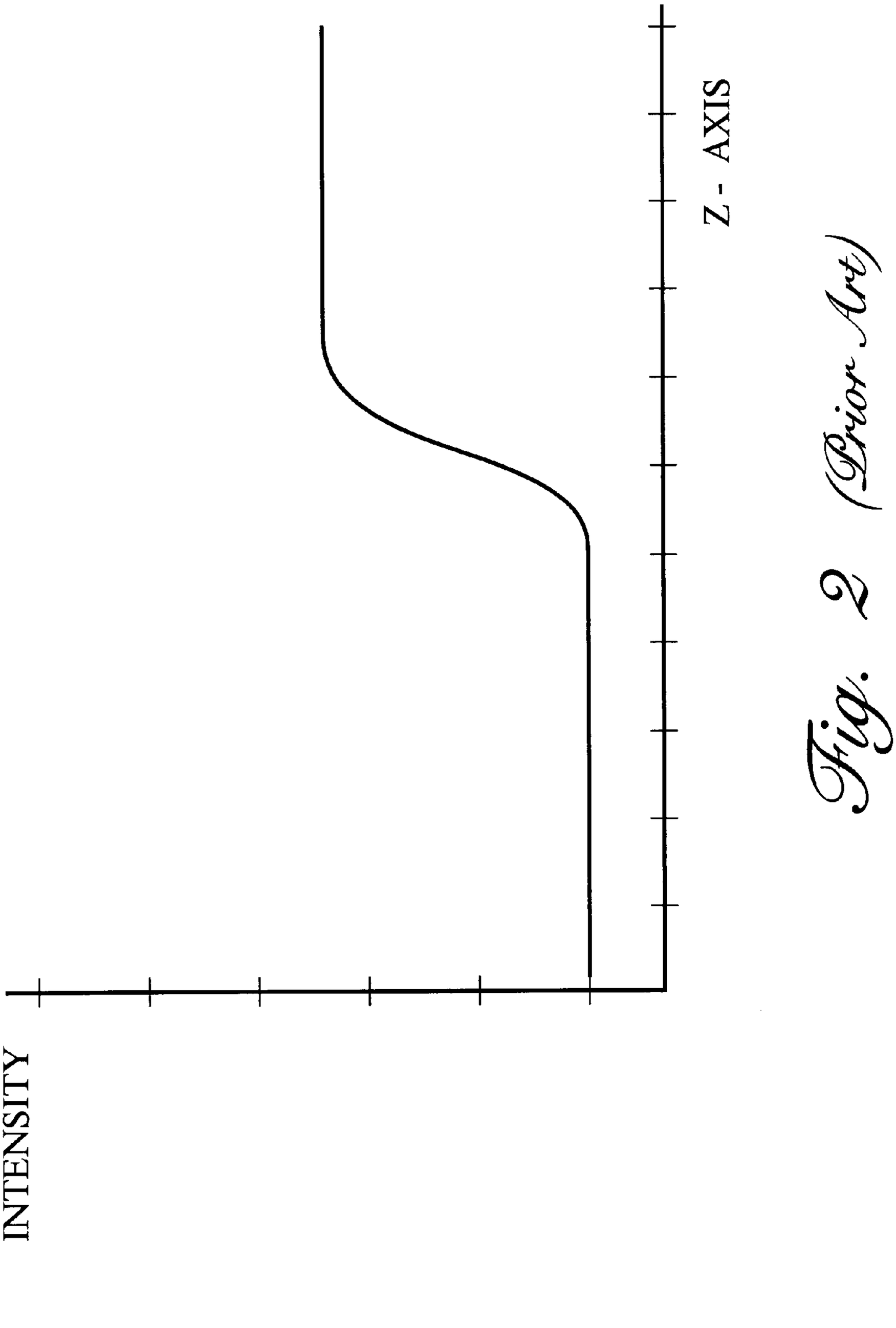

Fig. 2 (Prior Art)

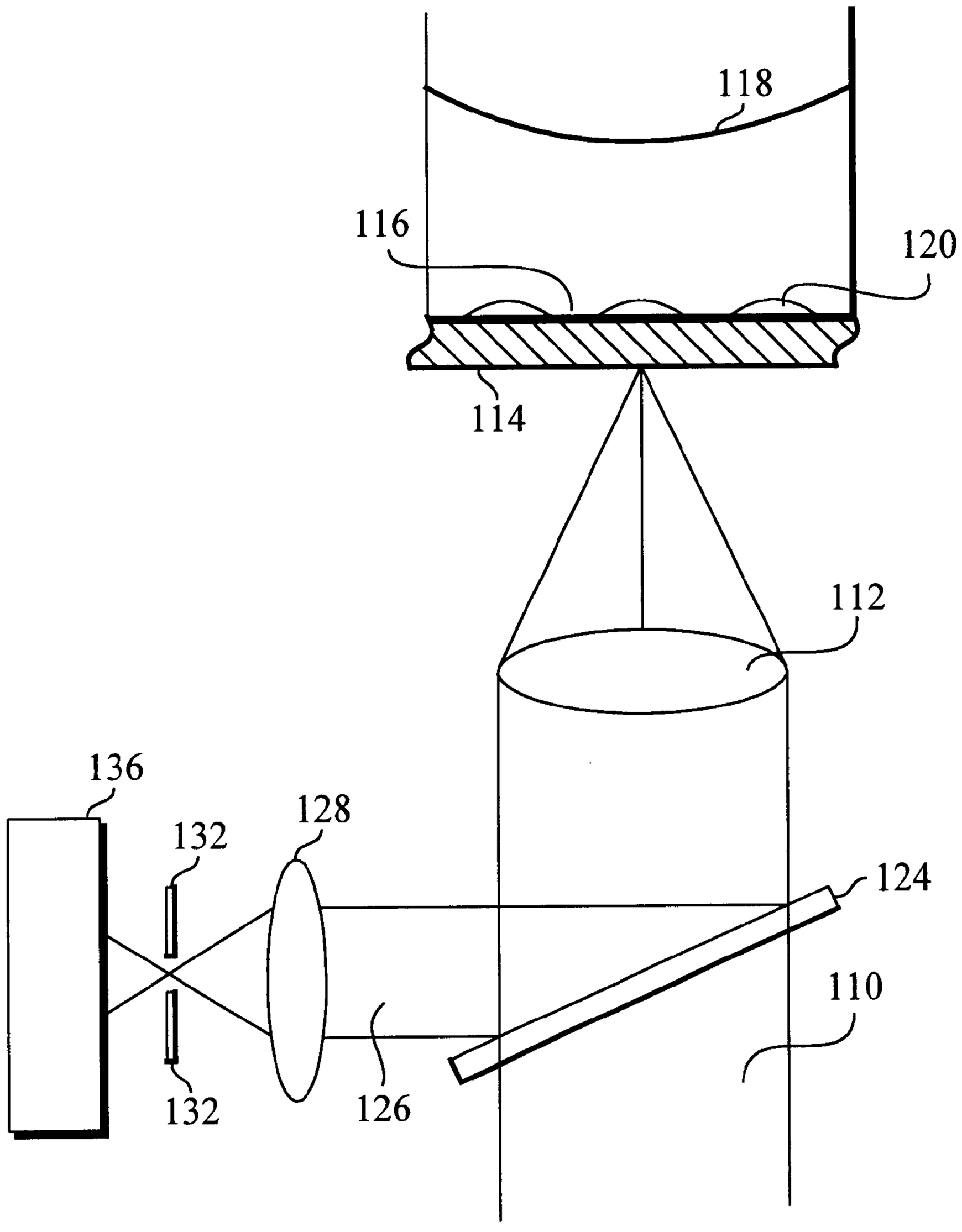

Fig. 3A

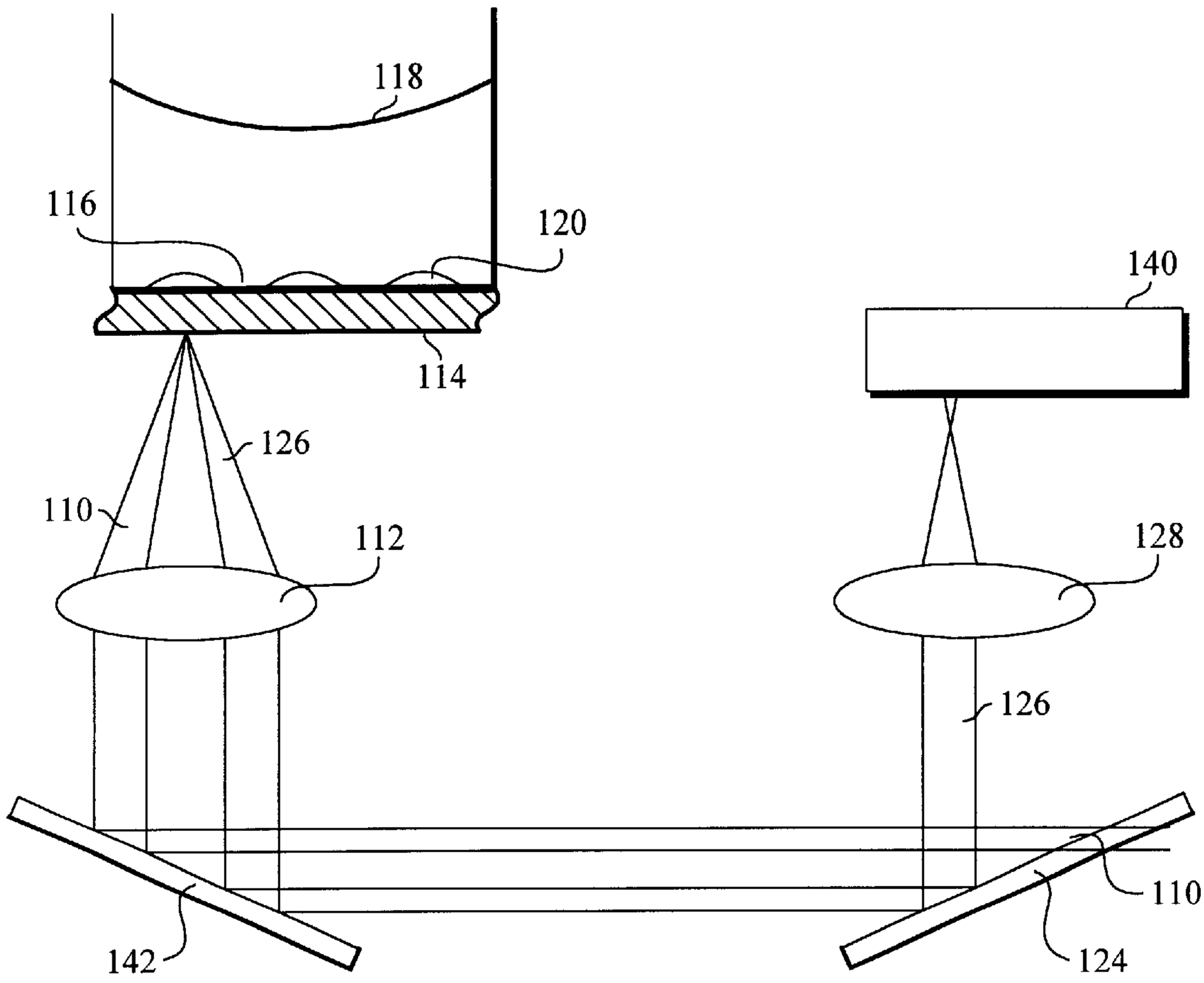

Fig. 3B

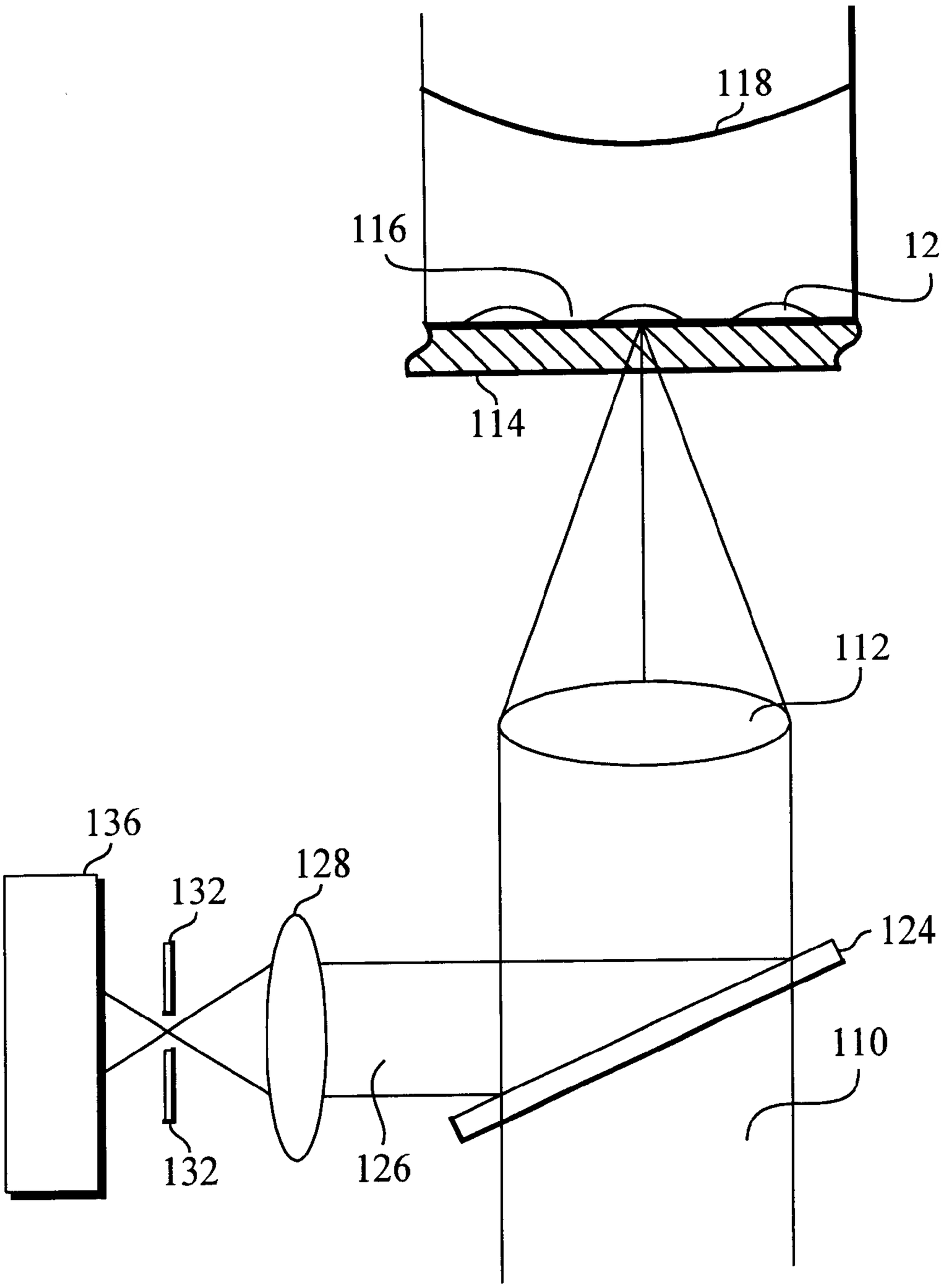

Fig. 3C

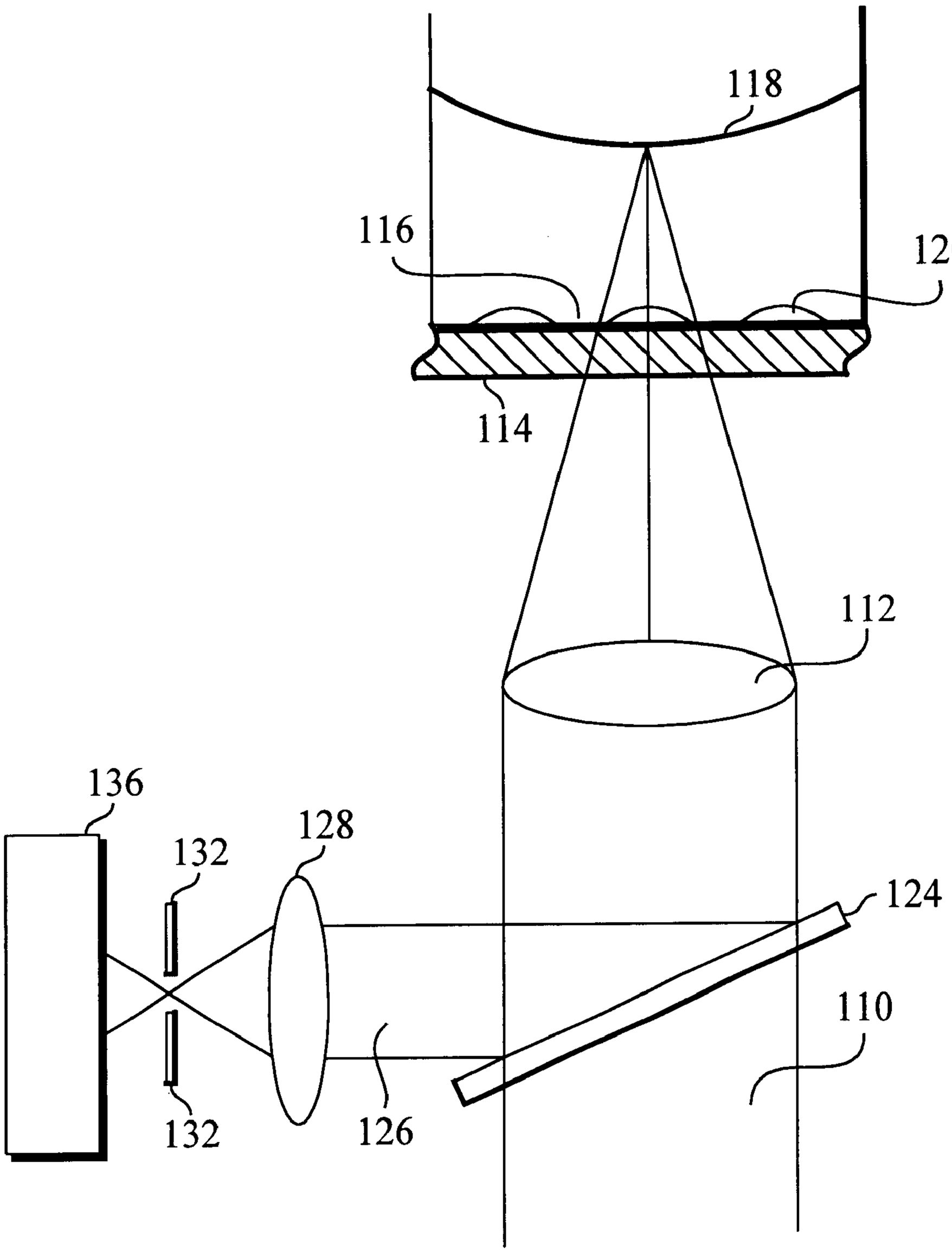

Fig. 3D

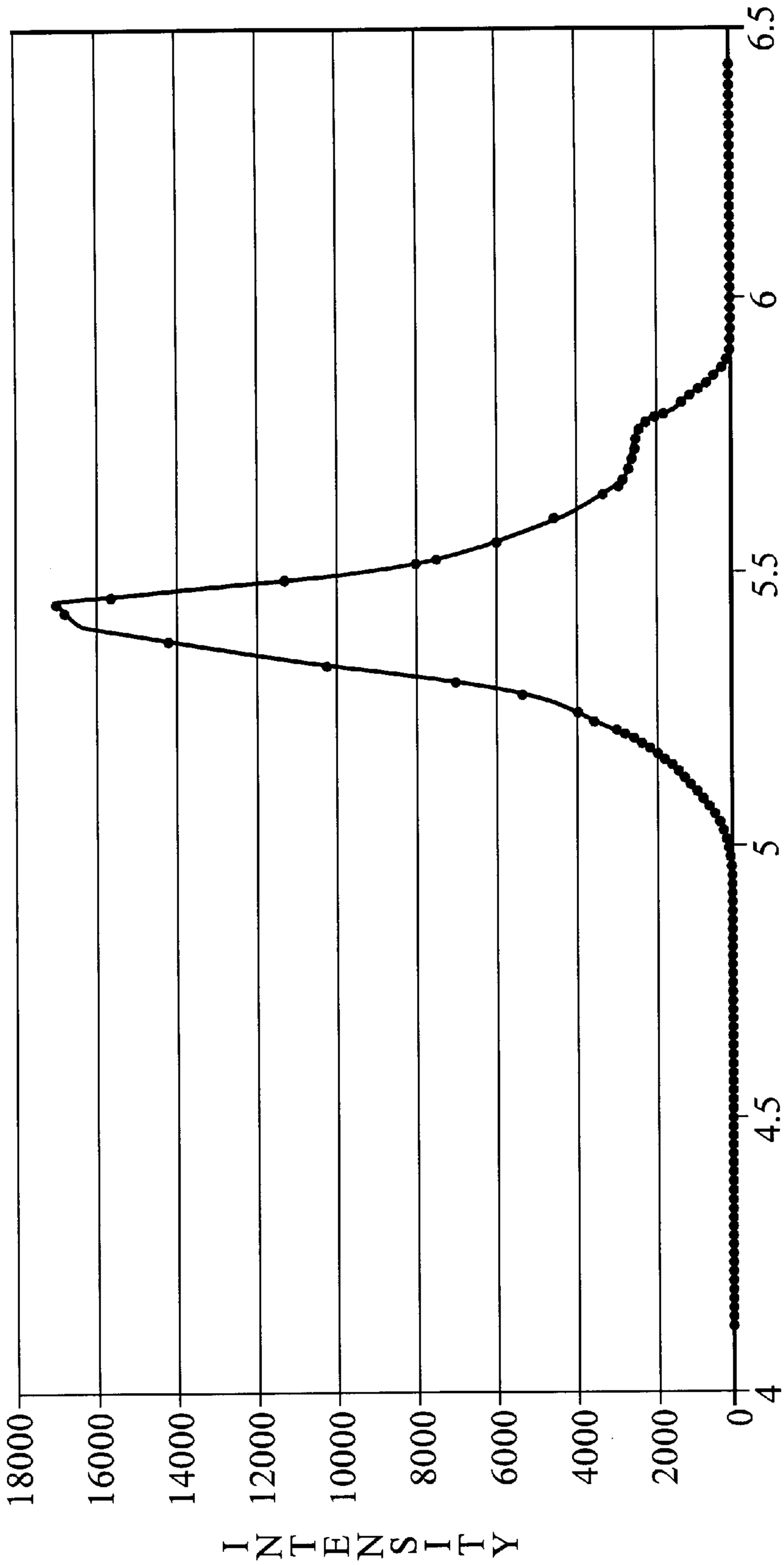
SPECULAR REFLECTION
INTENSITY
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Z POSITION
4
4.5
5
5.5
6
6.5

Fig. 4

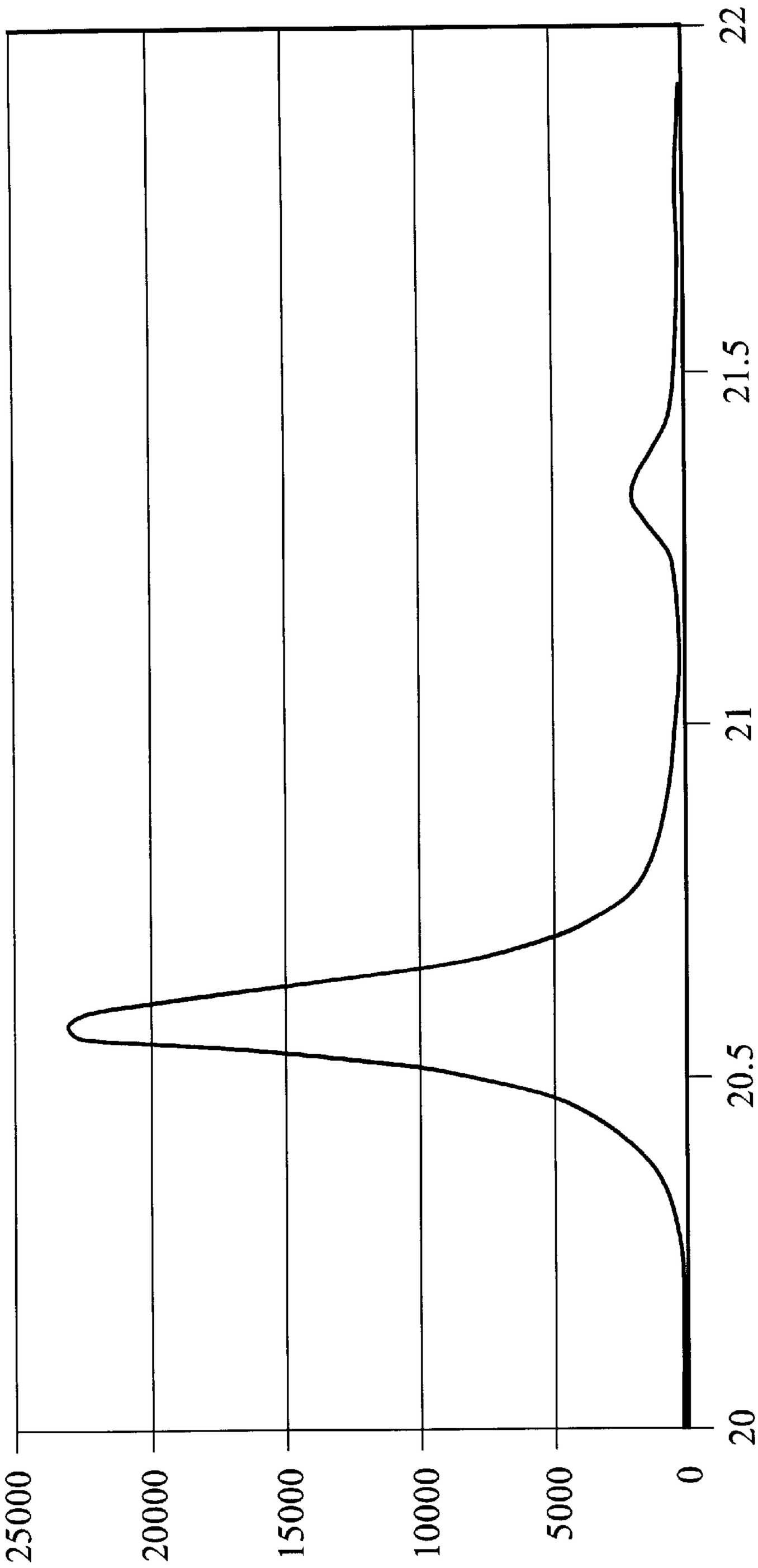

Fig. 5

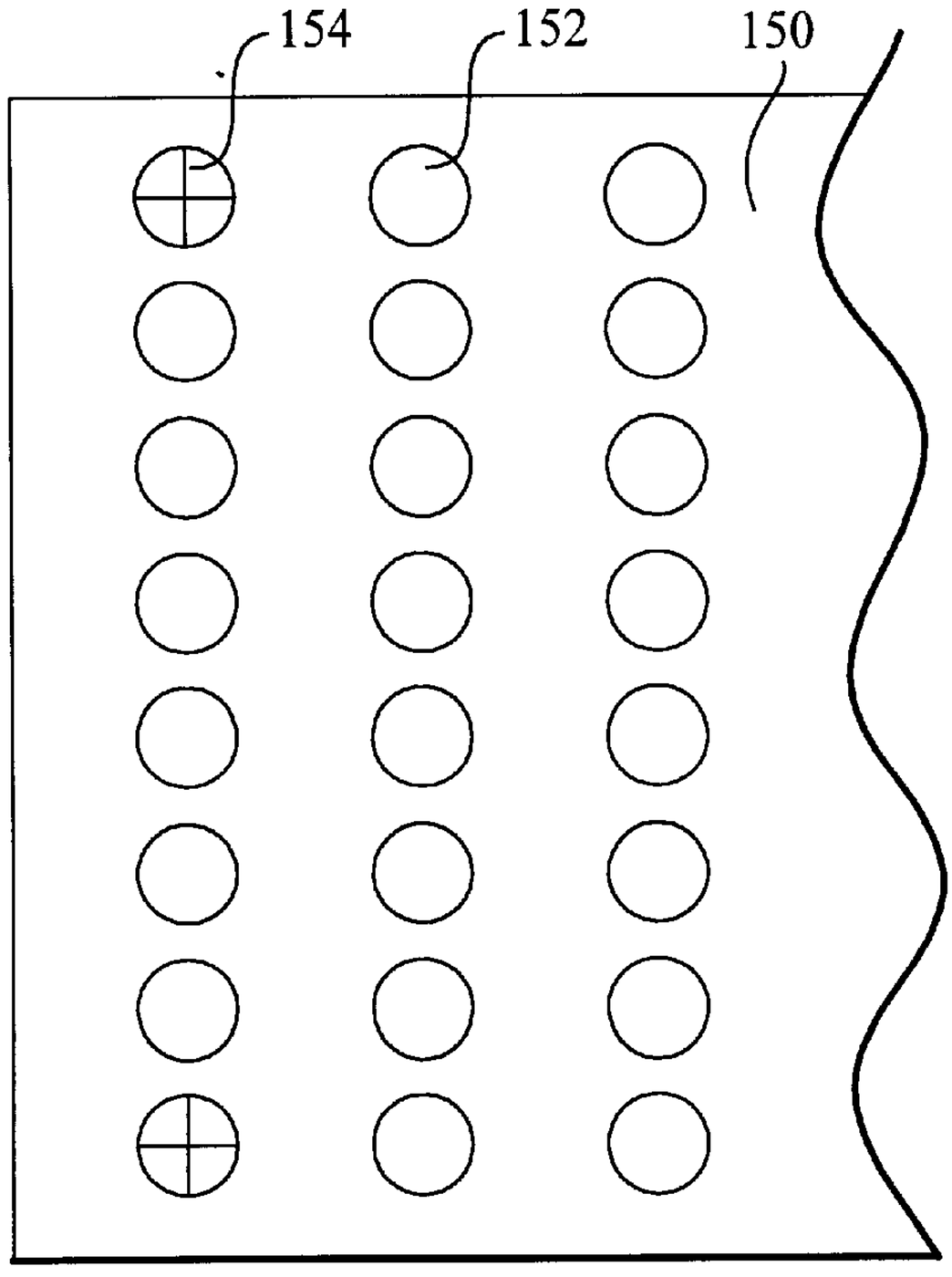

Fig. 6

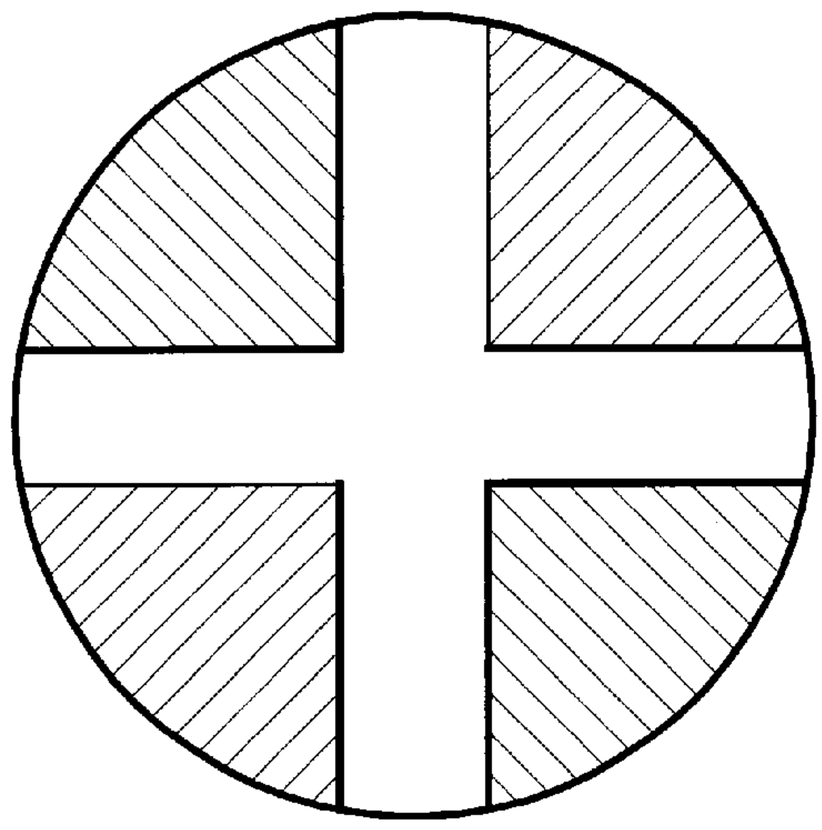

Fig. 7

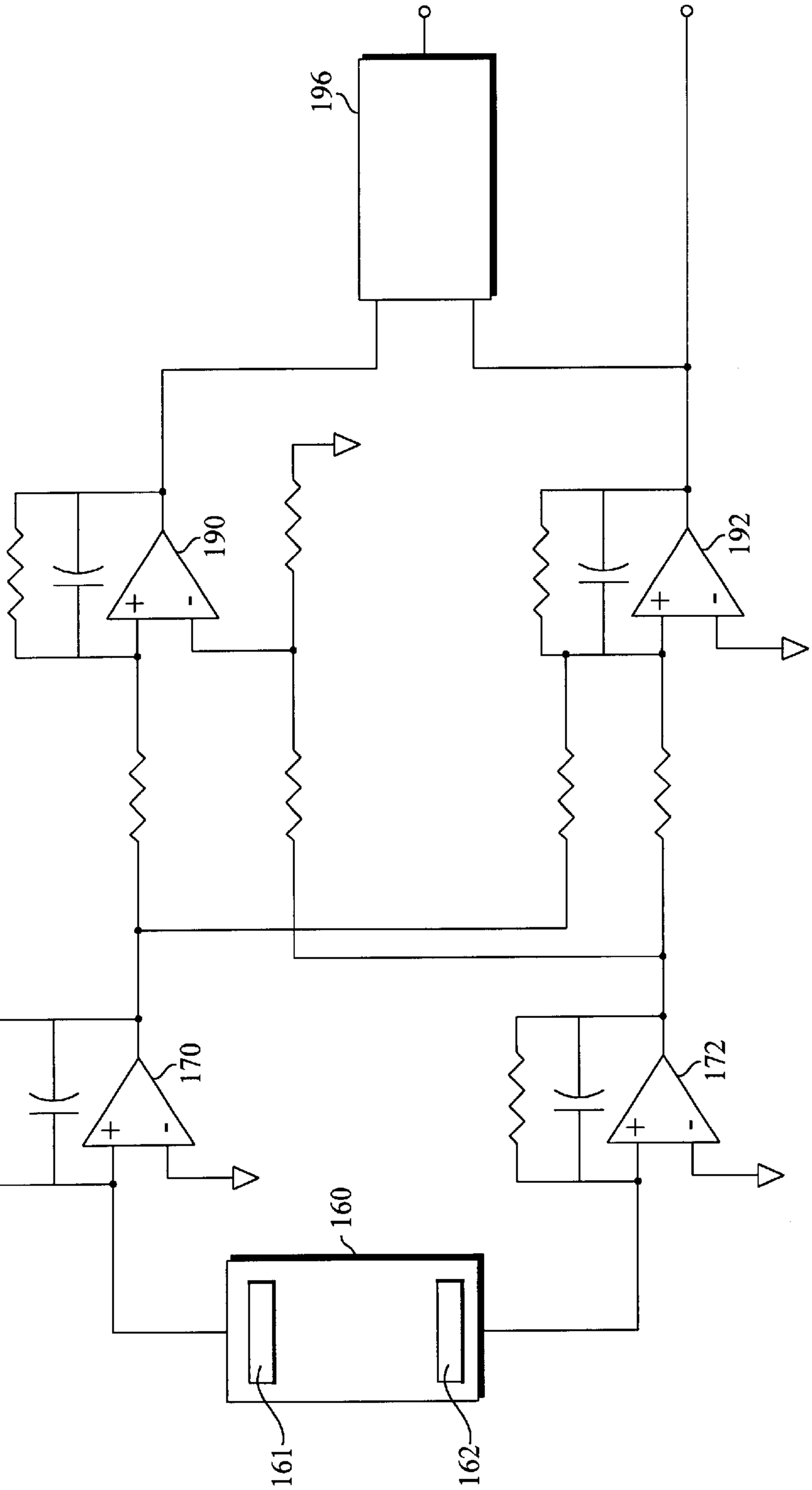

Fig. 8

OPTICAL AUTOFOCUS FOR USE WITH MICROTITER PLATES

CROSS-REFERENCE TO RELATED APPLICATION

This is a divisional application of application Ser. No. 09/245,782 filed Feb. 5, 1999, now U.S. Pat. No. 6,130,745, which is a continuation-in-part of application Ser. No. 09/226,842, filed Jan. 7, 1999, now abandoned

TECHNICAL FIELD

This invention relates generally to a method of focusing light for optical measurements into volumetric spaces and, more specifically, to an autofocus system for use with measurements in wells within microplates.

BACKGROUND ART

Numerous investigative assays use fluorescence to identify or enumerate a target of interest. Fluorescent detection has many applications in serology, cytology, microbiology, and histopathology. A chief advantage of using fluorescence is the low levels at which fluorescence can be detected, enabling highly sensitive tests. A second advantage with the use of fluorescence is that different fluorescent compounds have various different excitation and emission wavelengths. This allows for development of an assay of multiple targets in a single sample, with the assay for each target of interest associated with a different wavelength as a marker. An additional advantage is that fluorescence does not require the use of radioisotopes, resulting in reagents that are both safe to use and can be disposed of more easily.

One application of the use of fluorescent based assays is in the screening of compounds to identify potential pharmaceuticals. The process of drug discovery includes the screening of vast numbers of drug candidates made by combinatorial chemistry, requiring an extremely large number of assays. To simplify this process, assay procedures are often automated. Automation greatly increases screening throughput, allowing for more cost effective isolation of possible new drugs.

One method of automating the screening process involves introducing samples into a microplate well. These wells are often small, cylindrical receptacles arranged in rows in a rectangular array on a plastic sample plate. Commonly used microplates have 96, 384, or more wells per plate. Automated handling of these plates allows for higher throughput in screening samples in microplates.

Presently, assays using microplates and fluorescence detect emission in a two-dimensional reading of microplate wells. For example, U.S. Pat. No. 5,589,351 teaches a fluorescence analysis system that detects light transmitted from wells in a microplate. The light from a well is gathered and transferred to a reflector which sequentially directs light to a single detector. This system allows the sequential reading of rows of wells. The reading of wells is effected two dimensionally, with each well read as a unitary source of emitted light. This eliminates the ability of the assay to gather information on localized events within the well. U.S. Pat. No. 5,784,152 teaches another microplate reader that detects fluorescent emission. In this reader optical elements are included to enable tuneable detection to specific wavelengths. Detection is again effected in a two dimensional manner.

Three dimensional reading of microplate wells would allow more information to be gathered while using microplates. The targeted fluorescence often is localized on the bottom of microplate wells. The liquid in the microplate wells often contains additional unbound fluorescent reagents. In standard two-dimensional microplate fluorescent assays, detection of fluorescence on the bottom of a microplate well in a homogenous liquid is not possible. Fluorescent emission at the bottom of the well would be masked by the background fluorescence emitted from the unbound fluorescent compounds in the rest of the depth of the well. Simplified high throughput screens ideally would allow detection of the bottom layer in a well without removal of the unreacted fluorescent reagents.

To be able to detect fluorescence from the bottom layer of a microplate well requires the ability to automatically focus on a thin layer at the bottom of the well to excite fluorescent emission. This requires that the light source be able to focus on a 30 to 150 micron depth at the bottom of the microplate well. This focal depth would create a virtual capillary at the bottom of the well, a focal layer with the area of the well bottom but a depth of only 30 to 150 microns.

The geometry of microplates complicates attempts to focus on the bottom of microplate wells. A standard focal length would be possible if the plates were uniform to optical tolerance. However the location of the bottom surface of a microplate well is not uniform to 30 to 150 micron tolerances. To overcome this problem requires devising a method to precisely locate the bottom of a microplate well and focus on this location. In a high throughput system, this method must be rapid and accurate.

One known method of detecting a bottom layer in a microplate uses fluorescence detection to optically autofocus on a target layer within a microplate well. When the focal spot of laser light is below the well base top, minimal fluorescence will be detected. When the microplate is moved along the z axis of a microplate well (z axis is the longitudinal axis of the microplate well), the focal spot at some point begins to cross the well base top. The light from the focal spot will begin to excite fluorescent emission from some of the fluorescent compounds in the well as the focal spot enters the well. When the entire focal spot is above the well base top, a maximum fluorescent intensity is reached. FIG. **2** is a graph of the fluorescence intensity as the focal spot is moved into the well. The beginning of the maximum plateau of fluorescent intensity is a point where the location of the plate when the focal spot is entirely above the well base top. This has been used to refocus the beam within a microplate well. However, in practice this method has proved difficult to effect. The time required to use fluorescent graphing to determine focal spot placement within a well is not rapid enough for high throughput applications.

It is therefore an object of the invention to provide a method and apparatus capable of automatically focusing on a thin layer at the bottom of a microplate well. The focusing procedure should be rapid, accurate, and adaptable to fluorescence measurement in heterogeneous assays containing unbound fluorescent reagents. An additional object of the invention is to be able to use the focus method to determine the volume of liquid within the microplate well.

SUMMARY OF THE INVENTION

The above objects are achieved through a method and apparatus that uses a focused beam of light to optically sense a reference point on a microplate, such as the location of the top surface of the microplate well base, i.e. the surface defining the bottom of the well, and use this reference location to refocus the beam of light on a target within the

microplate well that is positioned in a defined relation to the reference location. A scan of the target layer allows an assay of a thin layer within a microplate well without optical interference from non-target locations within the microplate well, particularly where fluorescence is used to identify target substances.

In a first embodiment, this method is achieved by focusing a beam of light toward the material interface occurring at an optically detectable reference surface on the underside of a microplate. The reference surface is then moved relative to the focal spot of the beam of light. As this movement occurs, specular reflection from the reference surface is collected and directed through a focal aperture onto a light detector where the intensity of the specular reflection is measured. A peak intensity will be measured when the focal spot of the beam of light is on the reference surface, allowing a maximal amount of light to be directed through a focal aperture and onto a detector. Once the location of the reference surface is known, this location can be used to relocate the beam of light onto a target layer in the microplate well if the target layer is in a known relation to the reference surface. Once the focal spot is relocated to the target layer, fluorescence is excited and detected using a scan of the target layer.

In an alternate embodiment the autofocus method, the focal aperture and detector are replaced with a position sensitive detector. Again a focal spot of a beam of light is directed to a reference surface on the underside of a microplate well. The reference surface is moved relative to the focal spot of the beam of light but the detector is kept stationary. As this movement occurs, the specular reflection from the reference standard is directed onto the position sensitive detector having a sensitive area large enough to image the reflected focal spot during its motion. The position sensitive detector measures both the intensity of the reflected light and the position of the reflected light on the detector. As in the first embodiment, the measurement of the maximum detected light intensity correlates to where focal spot is on the reference surface. When the light reaches the maximum intensity of measured specular reflection, the light will also be detected at a position on the position sensitive detector. This position on the position sensitive detector is the location when the focal spot is targeted onto the reference surfaces. Once this position on the position sensitive detector is known, it can be used as a deterministic indicator for finding the position of the reference surface at other locations on the microplate. As in the first embodiment, once the reference surface is located, it is used to reposition the focal spot onto a target layer which is subsequently optically scanned.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows the optical elements of a fluorescence spectrometer with autofocus capability in accordance with the present invention.

FIG. **2** shows a graphic result of a prior art focusing method.

FIG. **3***a* shows the autofocus optical elements of FIG. **1** being used to detect the well base bottom.

FIG. **3***b* shows the optical system of FIG. **3***a* using an alternative detector.

FIG. **3***c* shows the autofocus optical elements of FIG. **1** being used to detect the well base top.

FIG. **3***d* shows the autofocus optical elements of FIG. **1** being used to detect the surface of liquid within a microplate well.

FIG. **4** shows a graph of the specular reflection of light as the bottom of a microplate well is moved along the longitudinal axis of the well relative to a focal spot of light beam.

FIG. **5** shows a second graph of the intensity of reflected light as the base of a microplate well is moved along the longitudinal axis of the well in relation to a focal spot of light beam.

FIG. **6** shows a section of a microplate with optically detectable registration marks.

FIG. **7** shows optically detectable registration marks of a microplate well bottom used in the microplate of FIG. **6**.

FIG. **8** depicts a circuit diagram of the circuit used with the position sensitive detector of FIG. **3***b*.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIG. **1**, a laser **10** produces laser beam **11**. In the preferred embodiment, a helium-neon laser is used. This laser can produce coherent light at a wavelength of 633 nm. The use of this wavelength light allows for optimal detection of fluorescent target compounds in biological samples since the light absorbance of typical biological samples is below this wavelength, hence autofluorescence from said samples is minimized. Laser light **11** is directed by a first steering mirror **12** through a first shutter **22**. The light next is directed by second steering mirror **14** through a second shutter **24**. Shutters **22** and **24** are included to comply with laser safety requirements. After passing through the second shutter **24**, the laser light next passes through laser line filter **26**. Laser line filter is included to suppress the plasma tube light but allow the laser light to be transmitted. This is needed because the plasma light interferes with the fluorescent light to be collected. The laser light passes through laser line filter **26** onto beam splitter **28**. Beam splitter **28** reflects some of the light into laser power sensor **16**. Power sensor **16** continuously monitors the power of the laser and is able to detect if the light power output is below the specification requirements. Additionally monitoring the light power would allow for normalizing the light output. The laser light that is not deflected by beam splitter **28** is transmitted through the beam splitter and through positive contractor lens **30** and negative contractor lens **32**. These lenses are used to shape the size of the laser light beam to produce the required focal spot size on the target microplate well. The laser light is then directed by laser dichroic splitter **34** onto oscillating galvo mirror **36**. The movement of oscillating galvo mirror **36** creates movement of the laser light along one axis. The light is directed by oscillating galvo mirror **36** through galvo relay lens **38** and is directed by relay fold mirror **56** through objective relay lens **54** which focuses the light. The purpose of the galvo relay lens **38** and objective relay lens **54** is to image the laser illuminated center of the galvo on the entrance pupil of the objective lens. In the preferred embodiment, relay fold mirror **56** directs laser light **11** in a direction such that the light is orthogonal to the plane in which the light had been previously directed. The light next passes through objective **51** and onto the target microplate well base bottom **53**.

This optical system allows for the two dimensional scan of the well base bottom **53**. The galvo mirror **36** enables movement of the focused light along one axis. The stage (not pictured) for holding microplate **53** enables movement of the focused light along another axis. Incremental movement of the stage creates raster line scan of the bottom of a microtiter plate. A raster line scan of the plane of a thin target layer contained in a microplate well enables detection of fluorescence over a large surface area with a limited depth of field.

Once the light is directed through well base bottom **53** and into microplate well **55**, light can be collected from two sources depending on where the focal spot of the light is targeted.

First, some of the laser light can be collected from specular reflection from some surface where there is a material transition, such as the transition from air to glass/plastic at well base bottom **53**. This light will be reflected back through objective **51** and objective relay lens **54** and will be directed by relay fold mirror **56** through galvo relay lens **38**. The reflected light is then directed by galvo mirror **36** onto laser dichroic splitter **34**. Because this light is reflected light it is the same wavelength as the original laser light **11** and will not pass through laser dichroic splitter **34** but instead will be directed through negative contractor lens **32** and positive contractor lens **30** onto beam splitter **28**. Beam splitter **28** directs the specularly reflected laser light through focus sensor lens **58** and towards aperture **50**. The reflected light that is focused will not be stopped by the aperture **50** and will be detected by sensor **52**. This is further explained in relation to FIGS. **3***a*, **3***b*, **3***c* and **3***d*.

Second, the laser light can be focused into the interior of a well **55** on microplate **53**. Contained within the well are fluorescent compounds that are excited by light of the wavelength of laser light **11**. When the laser light is directed onto the fluorescent compounds in the interior of microplate well **55**, fluorescent light of a known wavelength will be produced. In the preferred embodiment, the fluorescent compounds are Cy5™ and Cy5.5™, fluorophores that are available from Amersham Life Sciences, Inc. of Arlington Heights, Ill., and which emit fluorescent light maximally at 670 nm and 698 nm respectively. This light is emitted and some will enter into objective **51** and pass through objective relay lens **56** onto relay fold mirror **56**. The fluorescent emitted light is directed through galvo relay lens **38** and onto galvo mirror **36** which directs the fluorescent light onto laser dichroic mirror **34**. The laser dichroic splitter **34** is selected to reflect light of the wavelength of the laser light but allow through light of the wavelength of the fluorescence emission. The fluorescent light that passes through laser dichroic splitter **34** then passes into long pass filter **40**. Long pass filter suppresses any laser light that passed through laser dichroic splitter **34**. In the preferred embodiment, the long pass filter **40** passes light that has a wavelength above 645 nm and suppresses lower light wavelengths. The fluorescence light then is directed by fold mirror **42** through spatial filter lens **44** which focuses the fluorescent light through aperture **46**. The aperture blocks rays of the fluorescence emission that originate outside the collection volume of interest. The fluorescence light that passes through aperture **46** is then directed by fluorescence dichroic filter **48** which splits the light into two channels. Light below 680 nm is reflected by fluorescence dichroic filter **48** onto photomultiplier tube **62** which detects fluorescent light. Light above the 680 nm cut off passes through fluorescence dichroic filter **48** and is detected by photomultiplier tube **64**.

Homogeneous assays require limiting the depth of field of the scan of a microplate well to a thin target layer contained within the microplate well. Target cells or fluorescent beads are often located at the bottom of a microplate well. This is a result either of binding of the target to some compound associated with the well bottom or is the result of gravitational settling. Unreacted fluorescent compounds that remain in solution ordinarily would prevent the localized detection of fluorescence from a specific target layer within a microplate well. The background fluorescence from unreacted fluorescent compounds would effectively make the fluorescence from a target layer in a microplate well undetectable. It is necessary to locate the target layer in the microplate well and focus a beam of light on this location. This prevents the illumination and fluorescent emission from the area of the well that is not the target. The focus depth required ranges from 30 to 150 microns from the bottom surface of a microplate well. Because microplates are not designed to be optically flat to these tolerances, there must be some method of automatically sensing a reference point that has a known relation to the target layer.

A principal embodiment of the optical autofocusing is shown in FIGS. **3***a*, **3***c*, and **3***d*. FIG. **3***a* shows the autofocusing elements of FIG. **1** used to detect the well base bottom **114** of a microplate well base. A microplate well is formed by walls extending downward from the top of the microplate. The base of the well is formed by a layer of transparent glass or plastic material. A well base top surface of the well base faces the open top end of the wells. A well base bottom surface of this well base faces down from the open underside of the microplate. The target cells **120** have gravitationally settled to the bottom of the liquid in a microplate well. The layer of plastic or glass that comprises the well base has a well base top **116** where the target cells have settled and well base bottom **114**. A beam of laser light **110** is directed through beam splitter **124** and is focused by lens **112** into a focal spot. This focal spot is directed toward well base bottom **114**. Some of the light that is directed toward well base bottom **114** will be reflected by specular reflection back towards lens **112**. This light will be directed by beam splitter **124** through focus sensor lens **128** and toward focus sensor aperture **132**. Focus sensor aperture acts as a stop for light that is not focused. By changing the size of this aperture the size of the focal spot can be matched. The light that passes through focus sensor aperture **132** is detected by focus sensor **136**. This focus sensor could be a photodiode or other device that measures the intensity of the reflected light. To determine the location of well base bottom **114**, the microtiter plate is moved along the longitudinal axis of a microplate well. This results in the movement of the focal spot along this axis. When the beam's focal spot is not on well base bottom **114**, the specular reflection from well base bottom **114** will be more broadly scattered. This scattered light will be stopped by focus sensor aperture **132** resulting in less light detected by detector **136**. In contrast, when the waist of the focused beam is on well base bottom **114** the specular reflection from well base bottom **114** will be less scattered. This results in more light passing through focus sensor aperture **132** where the light is detected by detector **136**. FIG. **4** graphs the intensity of detected light as the well base bottom **114** is moved along the z axis relative to the waist of the a focused light beam. At position **5** on the z axis, the beam's focal spot is below the well base bottom of the plate and little light is focused through the focus sensor aperture. As the microplate is moved along the z axis and the focal spot of the beam comes closer to the well base bottom, more specular reflection from the well base bottom is detected. Near position **5.4** on the z axis, the maximum intensity of specular reflection is reached. This occurs when the focal spot of the beam of light is focused on well base bottom **114**. As the microplate is moved along the z axis, the intensity of specular reflection decreases as the focal spot of the beam moves into the interior of the well base. Using this method, the location along the z axis where the focal spot of the beam is focused on well base bottom **114** can be determined. This location is then used as a reference point for relocating the focal spot of the light beam to a target layer in the microplate well. The distance between well base bottom **114** and well base top **116** is the thickness of the plastic or glass material that comprises the well base. The dimension of this thickness is available from the manufacturer of the microplate. The waist of the light beam can be

moved to just above well base top **116** to locate cellular targets **120**. The optical system can then effect a scan of the target layers.

The autofocus method described in relation to FIG. **3***a* requires that the longitudinal axis of the focused light beam be substantially perpendicular to the well base bottom **114** of the microplate well bottom. This is effected by centering the galvo relay mirror **36** and holding the mirror stationary. The light is then focused by lens **112** perpendicular to the well base bottom **114**.

In an alternate embodiment seen in FIG. **3***b*, substitution of the detector allows for additional features in the autofocus system. In this embodiment, laser light **110** passes through beam splitter **124** and onto galvo relay mirror **142**. In this embodiment, galvo relay mirror **142** is not centered but is moved to a fixed position such that laser beam **110** is directed at a non-perpendicular angle in relation to well base bottom **114** and is again held stationary. Thus laser light **110** is directed through lens **112** and onto well base bottom **114** such that the longitudinal axis of the laser light is not perpendicular to well base bottom **114** but instead is directed at a non-right angle in relation to well base bottom **114**. Laser light **110** will be reflected by well base bottom **114** by specular reflection producing reflected light **126**. This light will pass through lens **112** and be directed by galvo relay mirror **142** onto beam splitter **124**. Because the reflected light **126** is the same wavelength as the original laser light **110**, the light will not pass through beam splitter **124** but instead is directed through focus sensor lens **128** onto position sensitive detector **140**.

One example of a position sensitive detector (PSD) is a silicon photodiode that produces an analog output directly proportional to the position of a light spot on the optically sensitive strip of the detector. This allows for simultaneous measurement of light intensity and light position on the detector. When the light strikes the photodiode, a photoelectric current is generated. The photoelectric current generated by the incident light is an input current that is divided into two output currents. The distribution of the output currents on the optically sensitive strip indicates the light position on the detector. The sum of the output current indicates light intensity.

The measurement of light intensity is used in the same manner as seen in FIG. **3***a*. To determine the location of a surface on the underside of a microplate, the well base bottom **114** is moved relative to the beam's focal spot. This will cause the focal spot to move from below well base bottom **114** onto well base bottom **114**. When this occurs the intensity of light detected by the PSD will increase as the increasingly small light spot allows more light to impinge within the width of the photosensitive element on the PSD. At the light intensity peak the waist of the beam will be focused onto well base bottom **114**. This can again be used as a reference location for relocation of the waist of the beam to a target layer within the microplate well. As the focal spot moves from below well base bottom **114** onto this surface and then into the well base, the intensity of the reflected light again forms a Gaussian curve with a similar shape to the curve shown in FIG. **4**. At the peak of the curve the intensity of reflected light is at a maximum indicating that the focal spot is on well base bottom **114**.

The width of the photosensitive strip on the PSD **140** determines what optical configuration is used with PSD **140**. If the width of the strip is very narrow, an aperture may be placed between focus sensor lens **128** and PSD **140**. The aperture functions as a stop for unfocused light, producing a Gaussian curve as the focal spot moves onto and off of well base bottom **114**. In contrast if the width of the photosensitive strip on the PSD is wide, the PSD **140** could be used without focus sensor lens **128**. The intensity of the light is measured as the specular reflection becomes collimated when focused on well base bottom **114**.

In addition to intensity of light, the PSD also measures the location of the light along the photo-sensitive length of the PSD. Since the light is directed at a non-right angle in relation to well base bottom **114**, moving of well base bottom **114** relative to the waist of the beam of light alters where the center of the focused beam strikes under surface **114**. This in turn alters where the reflected light impinges along the length of the photosensitive length of the PSD. Thus the light moves along the length of the PSD as the well base bottom **114** is moved relative to the focal spot. The point where the focal spot is on well base bottom **114** corresponds to light impinging on one location on the PSD. Light moves away from this location in one direction along the PSD when the focal spot is moved below well base bottom **114** and light moves in the other direction away from this location when the focal spot is moved above well base bottom **114**.

Using the PSD for focusing on a target layer within a microplate well requires first measuring both intensity of reflected light and the position of reflected light on the PSD as the microplate is moved along the z-axis. The peak intensity corresponds to the location where the focal spot is on the well base bottom. This requires a range of movement along the z-axis for one microplate well. Once these measurements are taken for one microplate well, the location along the length of the PSD that corresponds to the measurement for peak light intensity is known. Once this location is known it becomes a reference measurement that allows deterministic autofocus for other wells on the microplate. For each other well on the plate, a single measurement of specular reflection along the z-axis will correspond to a location along the photosensitive length of the PSD. This location along the PSD can be compared to the position along the PSD known to be the intensity peak. This indicates both the direction and amount the bottom needs to be moved to focus the waist of the beam on the well base bottom.

A circuit is used with the PSD to effect the relevant measurements. With reference to the optical position sensing detection circuit of FIG. **8**, light strikes a silicon photodiode **160** that provides an analog output directly proportional to the position of a light spot on the detector's optically active area. Output signals are taken at the electrodes **161** and **162**. The output from electrode **161** is fed to the operational amplifier **170** while the output from electrode **162** is fed to operational amplifier **172** in a path parallel to op amp **170**. The two operational amplifiers reside in parallel symmetric paths which are cross coupled. Op amp **170** is cross coupled to an input of op amp **192** which also receives an input from op amp **172**. Op amp **190** is cross coupled to op amp **172** which also receives an input from op amp **170**. In this way, signals are both added and subtracted such that in the upper channel, by appropriate inputs of op amp **190**, the output of op amp **190** is a subtractive signal, X1−X2, while in the lower channel, the output of op amp **192** is an additive signal, X1+X2. These two combined signals are fed to an analog divider **196** which takes the ratio of the two signals as X1−X2/X1+X2. The output of op amp **192**, X1+X2 gives the intensity measurement. The output of analog divider **196** gives the position of incident light on the detector normalized for light intensity.

FIG. **3***c* illustrates an alternate optical autofocus method to locate a target layer in a microplate well. In this method

the focal spot is directed toward well base top **116**. As in FIG. **3***a,* the specular reflection from this surface is collected and focused through focus sensor aperture **132** and detected by focus sensor **136**. As in FIG. **3***a,* the focal spot is moved along the z axis. Also as in FIG. **3***a,* the maximum intensity of specular reflection will occur when the focal spot of the beam is located at well base top **116**. This surface again can be used as a reference point for the location of the layer containing the target of interest. FIG. **5** illustrates the intensity profiles detected from the well base bottom and well base top as a well base is moved relative to a focal spot of a beam of light. The larger intensity peak at about 20.5 is the specular reflection from the well base bottom. The smaller second peak at about 21.4 is the reflection from the well base top. This second peak is much smaller than the first peak, indicating much less specular reflection from the well base top. This is a result of the lower index of reflection.

The lower index of reflection is a result of the different transitions from one material to another. The amount of light produced by specular reflection is determined by the formula:

$$I=(N-N')^2/(N+N')^2$$

N is the index of reflection of the first material that light passes through.

N' is the index of reflection of the second material that light passes through.

From this formula it can be seen that specular reflection will be greater for transitions between materials with indexes of refraction that are further apart. The well base bottom of the microplate well base is a transition from air, with an index of reflection of 1, to plastic or glass, with an index of reflection of 1.47 to 1.5. The relatively large difference between these two indexes of reflection creates the specular reflection as seen in the intensity peak at 20.5 seen in FIG. **5**. In contrast the well base top of the microplate well base is a transition from plastic, with an index of reflection of 1.47, to a liquid contained within the well, at an index of refraction of 1.33. The relatively small difference between the indexes of reflection creates the much smaller intensity peak at 21.4 seen in FIG. **5**. In some microplates the optical quality of the materials used is not sufficient to resolve the intensity peak from the specular reflection from the well base top.

Coatings may be added to a surface to alter the index of reflection and make detection of the upper surface by specular reflection feasible. For example, the well base bottom could be coated with a coating to decrease reflection. The antireflection coating is added to the well base bottom by vacuum evaporation deposition. Examples of compounds used for antireflection coatings include magnesium fluoride and lanthanum trifluoride. Alternatively the upper surface of the well could be coated with a coating to increase reflection. Compounds to increase reflection include metallic neutral density coatings which can be vacuum deposited on the well base top at the desired thickness to give the desired amount of reflection.

Another method to optically focus on a target layer in a microplate well uses optically detectable features added to the underside of a microplate that function as a reference point for the location of the thin layer in a microplate well. FIG. **6** shows a portion of the bottom of microplate **150** having these features. Optically detectable well **154** has an optically detectable feature enabling precise localization of the of the well base top. Once this surface has been detected it is used as a reference point for detecting the upper surface of well **152** that does not have the optical features.

An example of the optically detectable registration marks is shown in FIG. **7**. FIG. **7** shows the upper surface of a well bottom that has been physically altered to be optically detectable. The shaded sections indicate areas of the surface that have been roughened to decrease reflection from the surface. The unshaded areas indicate areas that have not been roughened and will have comparatively higher amounts of specular reflection. When the focal spot is focused on the optically altered bottom surface and scanned across the surface there will be a sharp transition as the focal spot moved from the rough area of the bottom to the non-rough area of the bottom of the plate. When the spot is unfocused the transition will be less sharp.

The optical reference marks can be located on the well base bottom, on the well base top, or at another location on the underside of a microplate as long as this location has a defined relation to the location of the well base. The optically detectable reference may be the scribe marks described or could alternatively be bar code indicia, or patterned reflected coating (such as the neutral density coatings previously described).

FIG. **3***d* shows the autofocusing elements of FIG. **1** used to detect the liquid surface **118**. Once the well base top **116** of the bottom of the well is located, the focal spot of the light beam can be moved along the z axis toward the top of the well. When the focal spot is proximate to the liquid surface, specularly reflected light can be detected by focus sensor **136**. As with the other surfaces, as the focal spot is moved toward surface **118** the intensity of the reflected light increases to a maximum point when the focal spot is located at liquid surface **118**. Once the location of the liquid surface **118** and microplate well base top **116** are known, the volume of liquid in the well can be calculated if the geometry of the well is known.

We claim:

1. A container for analysis of a target layer using an optical system, the container comprising:

a rigid, transparent surface on said container; and

at least one registration mark positioned in a defined location on said surface, wherein said at least one registration mark is optically detectable by detection of specular reflection, wherein said at least one registration mark is adaptable for use as a reference location for determining the position of said target layer within the container.

2. The container of claim **1**, wherein the at least one registration mark is a patterned reflective coating located on the surface.

3. The container of claim **1**, wherein the at least one registration mark is a pattern of scribe marks of greater and lesser reflectivity located on the surface.

4. The container of claim **1**, wherein the at least one registration mark is bar code indicia located on the surface.

5. A microplate for detecting the position of a target layer using an optical system, comprising:

a block having a plurality of depressions forming wells in an array within said block, each well having a base;

a rigid transparent layer forming a bottom surface of said wells in known relation to the base of each well; and

at least one optically detectable registration mark positioned on an underside of said microplate in defined relation to a well base and adaptable for use as an optical reference location for determining the position of said target layer within the microplate wells.

6. The microplate of claim **5**, where the at least one registration mark is a patterned reflective coating located on the underside of the microplate.

7. The microplate of claim **5**, where the at least one registration mark is a pattern of scribe marks of greater and lesser reflectivity located on the underside of the microplate.

8. The microplate of claim **5**, where the at least one registration mark is bar code indicia located on the underside of the microplate.

9. The microplate of claim **5**, wherein said at least one registration mark is located on at least one well base bottom.

10. The microplate of claim **5** wherein said at least one registration mark is located on at least one well base top.

11. A container for analysis of a target layer using an optical system, the container comprising:

a base including an upper rigid, transparent surface and a lower rigid transparent surface on said container; and

at least one registration mark positioned on one of said surfaces in a defined location relative to said other surface, wherein said at least one registration mark is adaptable for use as a reference location for determining the position of said target layer within the container.

12. The container of claim **11** wherein said registration mark is positioned on said upper surface.

13. The container of claim **11** wherein said registration mark is positioned on said lower surface.

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